HUMIDITY CONTROL IN RESIDENCES

John Trowbridge
Engineering Associate
City of Austin
Austin, TX

John Peterson, PE
Research Associate
Center for Energy Studies
University of Texas at Austin
Austin, TX

ABSTRACT

Maintaining relative humidity below 60% for residential houses in humid climates promotes a healthy indoor environment. Yet, for such homes, these lower humidity levels are difficult to maintain with conventional recirculation air conditioning units. By introducing a separate vapor compression unit to pre-condition outside air, indoor relative humidity can be controlled. This new air conditioning system combines a ventilation unit with a conventional recirculation air conditioning unit. Although successful in maintaining indoor humidity levels below 60%, the new air conditioning system will require more electric energy to provide the additional dehumidification. However, this penalty is shown to be offset by reductions in sensible load during a summer week, which should result in lower energy consumption and peak electric demand during that period. The performance of this new air conditioning system is demonstrated using FSEC 3.0, a building energy simulation program developed by the Florida Solar Energy Center, to simulate the heat and moisture transport occurring within a prototypical residence located in Austin, Texas.

INTRODUCTION

In recent years, there has been an emphasis on reviewing and assessing the health of buildings in order to evaluate its impact on worker productivity and absenteeism. Research has demonstrated the close relationship and positive effect a healthy building has upon improved worker effectiveness and well being. Such studies have concluded that a properly installed HVAC system, which introduces outdoor air with supply air, will provide relief to building occupants who suffer from physiological ailments caused by poor indoor air quality. While commercial buildings often induce ventilation through operation of HVAC equipment, residences rely on natural infiltration as their source of ventilation to maintain good indoor air quality. Unfortunately, infiltration may not be the solution for improving indoor air quality in residences located in humid climates. In fact, infiltration of moist, mild air, may be a significant factor in creating an environment which reduces occupant comfort while increasing the potential for allergenic and pathogenic illness (Trowbridge et al., 1994).

Following a basic philosophy introduced by Kohloss (1981), it is the intent of this paper to propose a new residential air conditioning system that, in part, ventilates conditioned outside air into the home. This system introduces pre-conditioned ambient air into the living area at a dew point temperature sufficient to treat the entire latent load with a vapor-compression air conditioning ventilation unit, while operating a conventional vapor-compression recirculation air conditioner to meet the remaining loads. The proposed arrangement of equipment is shown in Figure 1. The key concept embodied within the ventilation configuration is that the ventilated air enters the space at a rate sufficient to overcome all infiltration, so that the conditioned room is pressurized. Because the conditioned ventilation air is drier than the outside air, reduction of interior humidity to below the recommended level, i.e., a maximum of 60% relative humidity (ASHRAE 1989), is achieved thereby improving the health and comfort of the building occupants (Trowbridge et al. 1994).

METHOD

The use and effectiveness of the ventilation configuration in the following analysis is demonstrated using the multipurpose program FSEC 3.0 (Kerestecioglu et al. 1988) developed by the Florida Solar Energy Center . This computer program is able to model both heat and moisture transfer in building materials using a finite element computational scheme. For simplicity, all finite elements are of one dimension, requiring the assumption of homogeneous materials and uniform heat and mass transfer through walls. Additional subprograms are employed to evaluate the effect of an air conditioner on the space's psychometric properties.

Proceedings of the Ninth Symposium on Improving Building Systems in Hot and Humid Climates, Arlington, TX, May 19-20, 1994

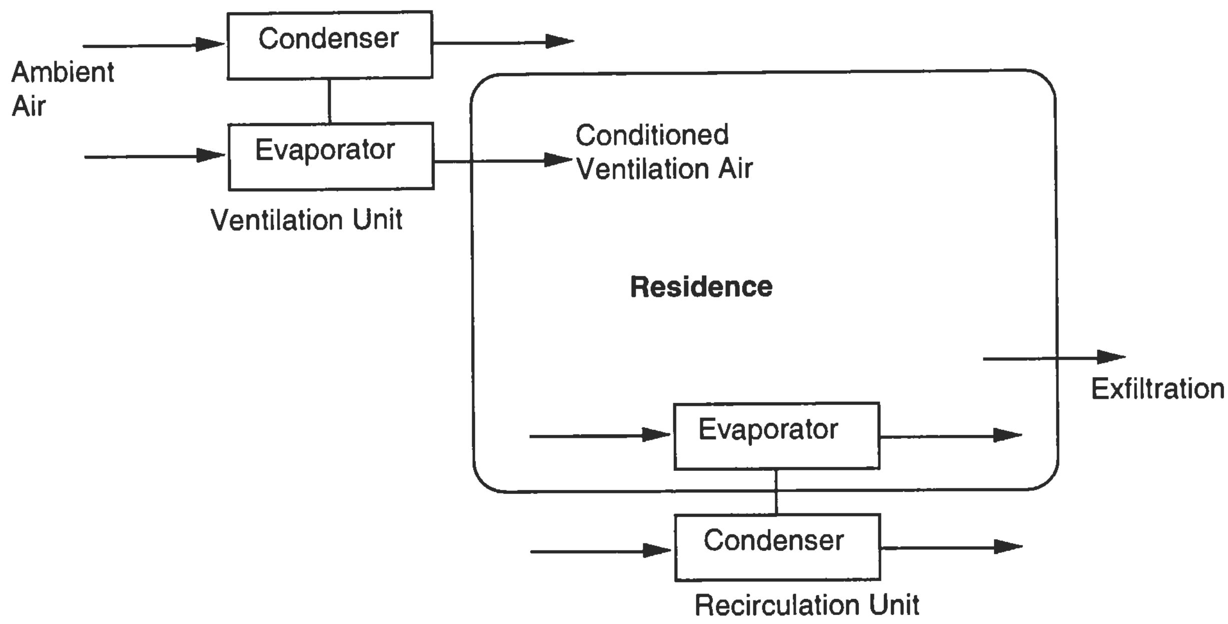

Figure 1 Ventilation Configuration

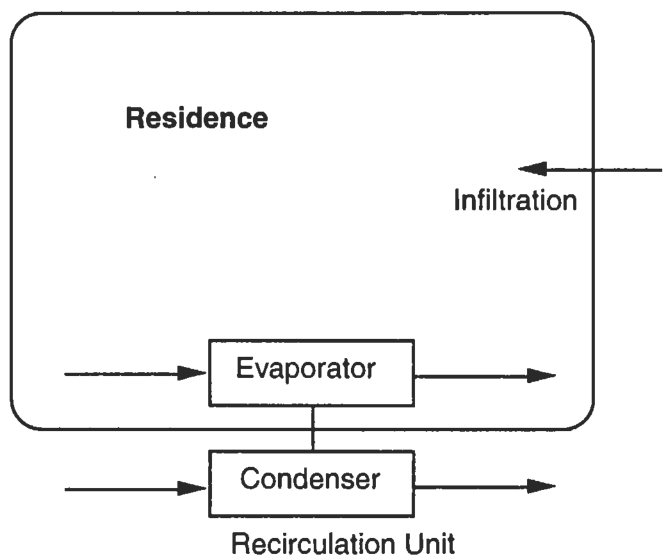

Figure 2 Base-Case Configuration

Space conditions and cooling loads for the ventilation configuration are compared with the base case configuration shown in Figure 2, which incorporates a conventional recirculation air conditioner. Although performance of recirculation units in both configurations is derived from algorithms fitted to data gathered in test for application, such testing has yet to be accomplished for the ventilation unit. In the ventilation configuration simulations, performance of the ventilation unit is characterized by the cooling loads calculated to cool and dehumidify air to 53 °F (11.7 °C). Even though models are available to calculate unit power draw of the recirculation units, only the cooling loads are reported rather than power use. This method of reporting allows a direct comparison between the performance of the base case and ventilation configurations, since power use has yet to be determined for the ventilation unit.

BASE-LINE RESIDENCE

The residence simulated in these comparisons is representative of typical small homes found in Austin, Texas. Overall dimensions and construction features are displayed in Figure 3. The residence comprises 1,600 ft^2 (149 m^2) of conditioned living area and 6,660 ft^3 (188.6 m^3) of unconditioned attic space. The exterior construction includes four identical unshaded walls, inset with 40 ft^2 (3.7 m^2) of windows in each orientation. Within the house is 1,522 ft^2 (141.45 m^2) of gypsum drywall representing interior walls. All of the surfaces and construction materials, through which heat and mass are transferred, are characterized by their respective properties in Trowbridge et al. (1994).

Internal gains within the conditioned space include sensible and latent load generation from lighting, people, and equipment; continuous sensible and latent heat generation totals, 3,040 Btu/h (0.891 kW) and 614 Btu/h (0.180 kW), respectively. Infiltration is assumed constant at 0.75 air changes per hour. Cooling set points of 75 °F (23.9 °C) and heating set points of 70 °F (21.1 °C) are specified in these simulations. Increases in internal energy from solar radiation through windows are distributed 20% to indoor air and 80% to the floor and walls.

CONFIGURATIONS OF AIR CONDITIONING EQUIPMENT

A conventional air conditioner with a rated capacity of 2.5 tons (8.6 kW) and sensible heat ratio (SHR) of 0.77, recirculates 875 CFM (413 ℓ/s) of conditioned air through the base-line residence in the base case configuration of equipment. This specification is based upon a rule-of-thumb sizing criteria of 600 ft^2 per ton (15.9 m^2/kW). This criteria is the minimum used in The City of Austin's Home Energy Loan Program administered by Austin's Environmental and Conservation Services Department. The air conditioner cycles to maintain a thermostat temperature set point.

The ventilation configuration couples a 1.0 ton (3.5 kW) vapor-compression ventilation unit delivering 160 CFM (75.5 ℓ/s) of conditioned outdoor air with a 1.5 ton (5.3 kW) recirculation vapor-compression unit recirculating 675 CFM (319 ℓ/s) through the base-line residence at a SHR of 0.74. The ventilation unit runs continuously when it operates and the recirculation unit cycles to maintain a thermostat temperature set point.

The capacities of the air conditioning units in both configurations are obtained when testing for rating with indoor air entering at 80 °F (26.7 °C) dry-bulb and 67 °F (19.4 °C) wet-bulb and ambient dry-bulb temperature of 95 °F (35.0 °C).

WEATHER DATA

Ambient information used in the study was secured from Austin's Typical Meteorological Year weather files for the months of April and August and are shown in Figures 4 and 5 respectively. Weather data for late April represents a series of characteristic days in which temperature is mild, but relative humidity is high. Weather data for August demonstrates extreme temperature but relatively mild humidity conditions. These weather patterns typify those observed for Spring and Summer in Austin, Texas. Hourly weather data are used to calculate building loads.

RESULTS

April Simulations

The need for additional dehumidification during Spring in Austin was illustrated by Trowbridge et al. (1994). Consider their results presented in Figure 6 depicting the indoor relative humidity during a continuous 12-day period in April for the base case configuration controlled by a thermostat. Elevated levels of indoor humidity result from the infrequent air conditioner operation that accompanies ambient temperatures that seldom exceed 80 °F (26.7 °C). According to Trowbridge et al., passive approaches that include the effect of reducing infiltration or

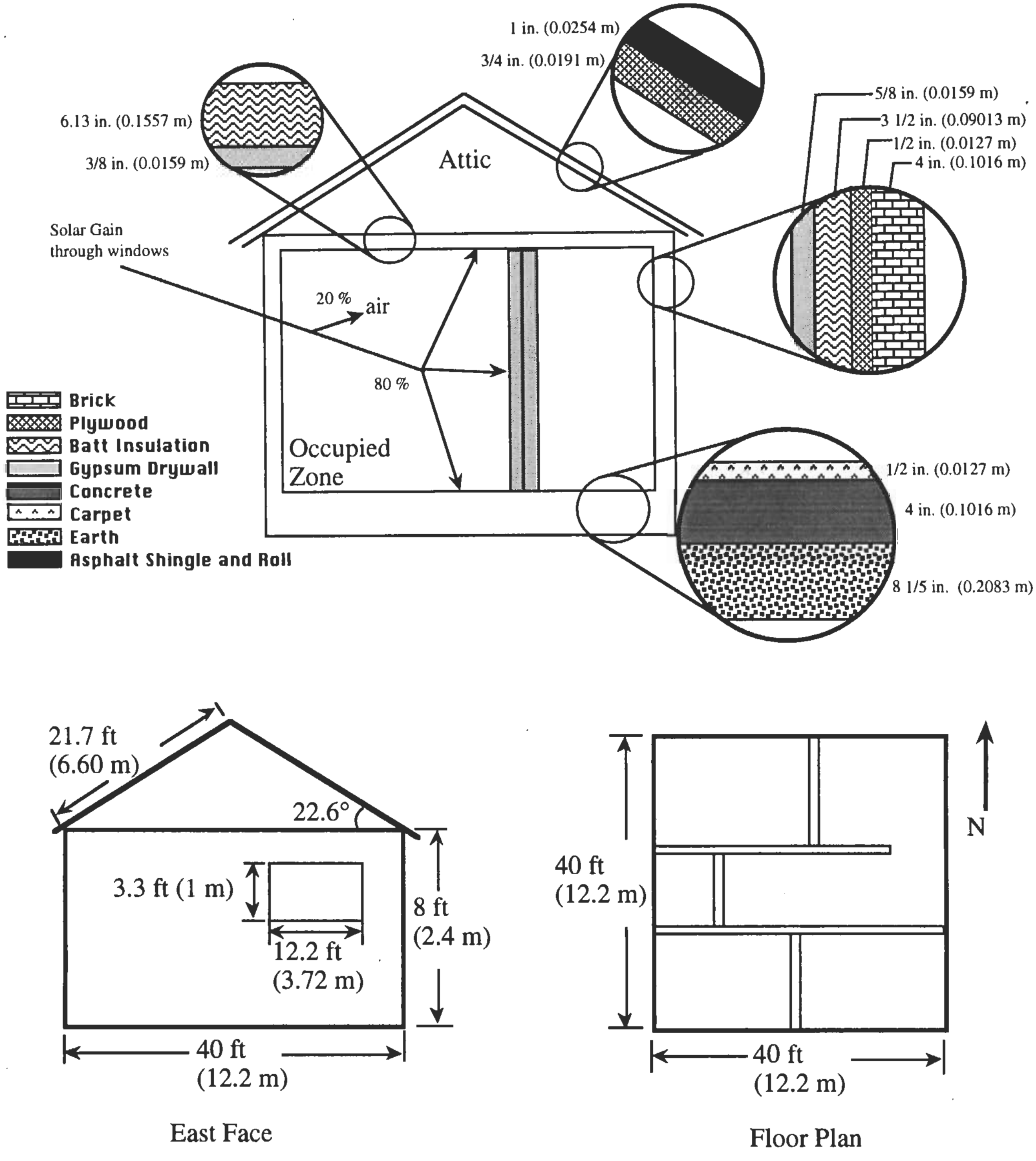

Figure 3 Base-Line Residence and Building Materials of Construction

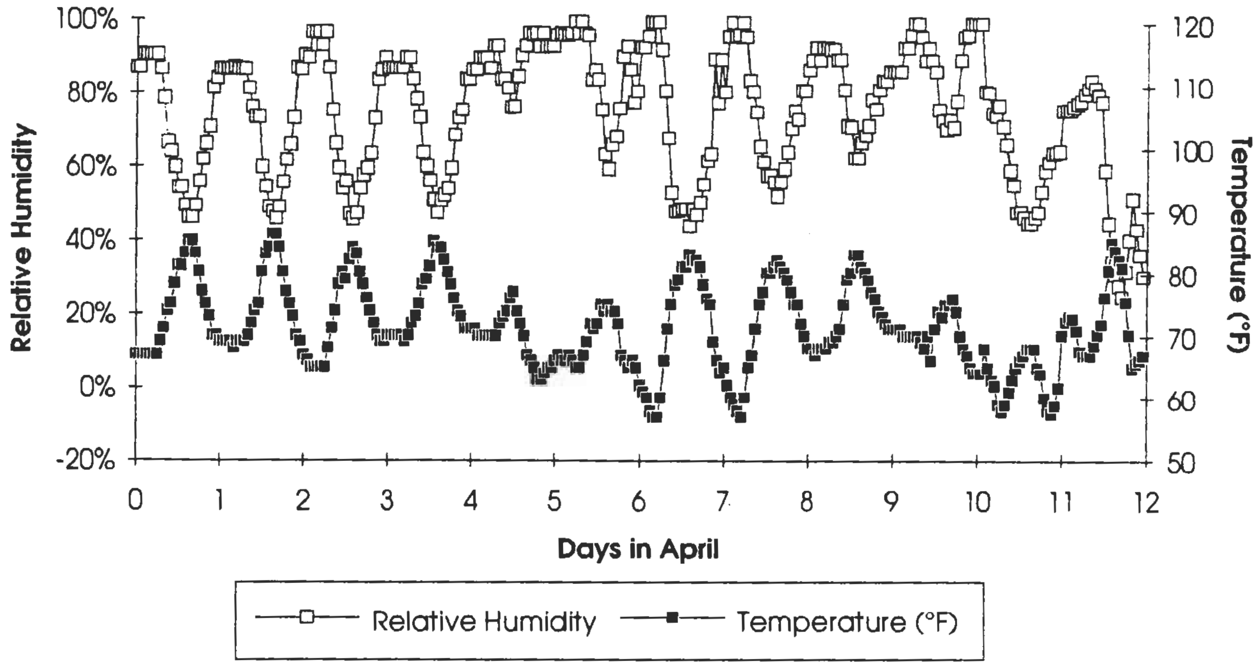

Figure 4 Ambient Conditions for April

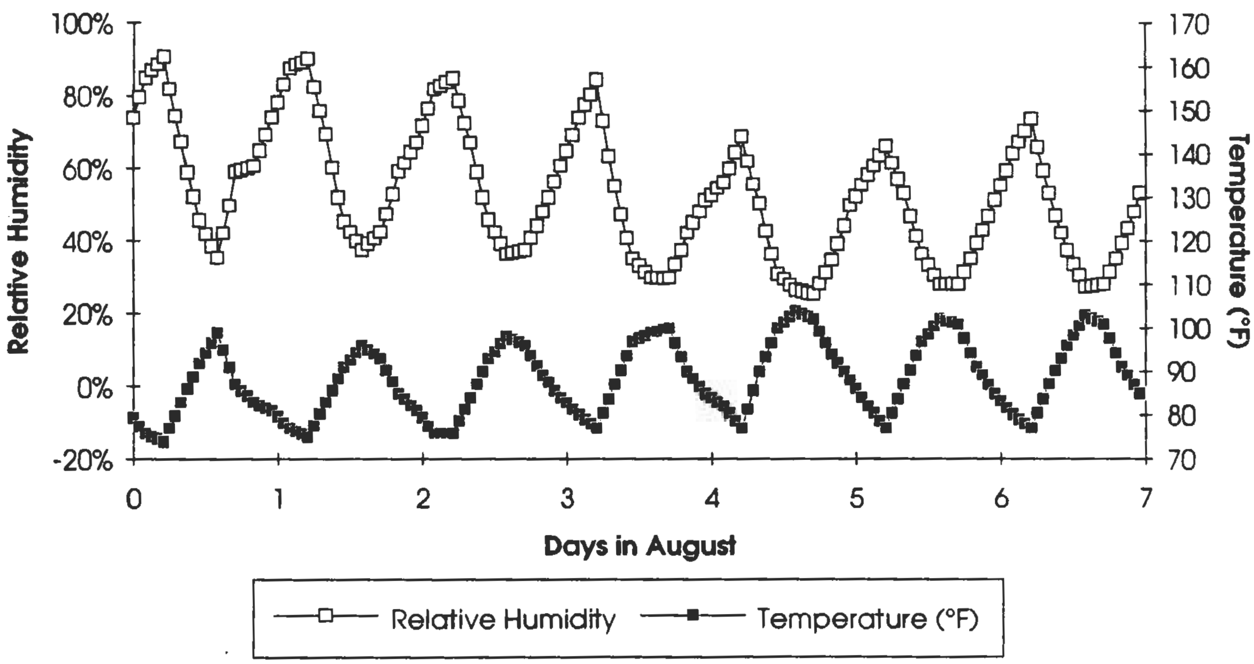

Figure 5 Ambient Conditions for August

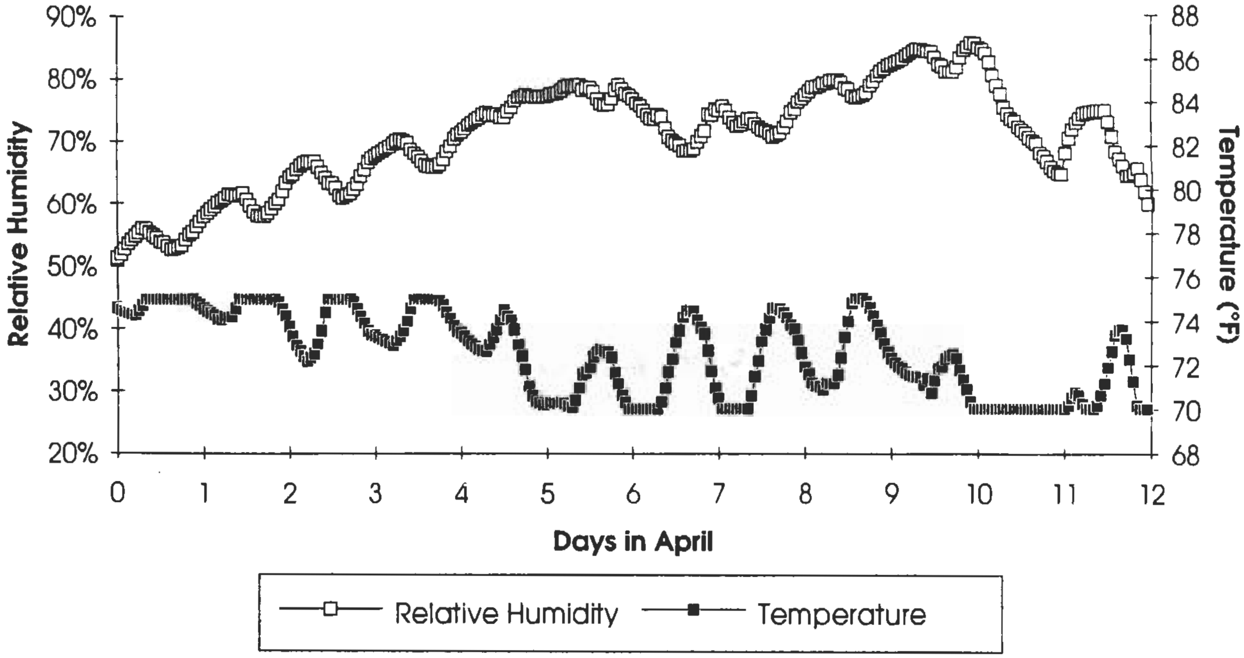

Figure 6 Base-Case Configuration Operating in April

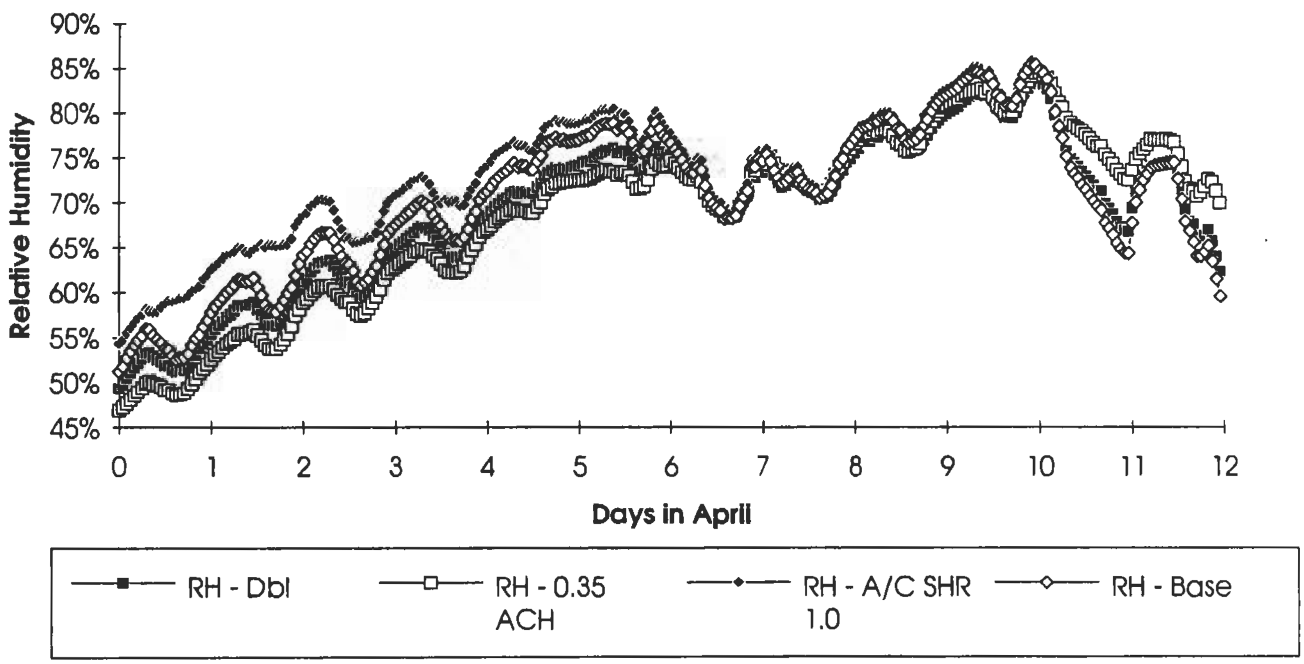

Figure 7 Indoor Relative Humidity for Passive Humidity Reducing Strategies in April.

doubling the moisture capacitance of the residence provide little relief as shown in Figure 7. Reducing infiltration only delays the inevitable as consistently high ambient relative humidity overcomes the space. Increasing the moisture capacitance fails to mitigate the problem of elevated levels of indoor humidity because the mass can not be sufficiently regenerated by the infrequent operation of the air conditioner. Since the recirculation air conditioner in the base case configuration is the only source of dehumidification for the residence, there is no other means of lowering the indoor humidity that greatly exceeds the recommended ASHRAE maximum of 60%.

To provide additional dehumidification, a ventilation unit is employed within the ventilation configuration to condition outside air and deliver it into the residence at a rate sufficient to overcome infiltration. Figure 8 shows this to be a successful strategy in that the interior humidity levels are reduced below 60%. However, an increased expenditure of energy is required to maintain desirable indoor conditions. As shown in Figure 9, energy is required to wring moisture from outdoor air and additional energy is expended when this air is heated to maintain a heating set point of 70 ^{o}F (21.1^{o} C).

August Simulations

For the warmer month of August, performance of the ventilation configuration is presented and compared to the base case configuration in Figures 10 and 11. The air conditioner in the base case configuration cycles over the entire day to maintain a constant thermostat setting of 75 ^{o}F (23.9 ^{o}C). Setting the thermostat to a higher setting in this configuration is not advisable because the cyclic control of oversized air conditioning units leads to clammy indoor conditions within residences located in humid environments. Oversized cyclic units normally cycle off about the time the unit balances out and achieves maximum moisture removal capacity. During the transient period between startup and shutdown, the unit can average 4-8% moisture removal under light load, far below manufacturer's published performance which represents steady-state operation. Homeowners overcome these unpleasant conditions by lowering the thermostat to keep the cyclic unit operating longer. This, of course leads to higher energy consumption and larger demands for power from the electric utility.

In the ventilation configuration simulations, the ventilation unit operates continuously from 12 am. to 6 am. and the recirculation unit cycles to maintain a constant thermostat setting from 6:01 am. to 11:59 p.m. Only the ventilation unit operates between the hours of 12 am. and 6 am. and only the recirculation unit operates during the remaining hours of the day. This control of air conditioner operation implements a strategy for reducing electric demand by turning off the ventilation unit during periods of peak electric demand and shifting load from on-peak to off-peak periods. Clammy and unpleasant conditions do not result because the air conditioning units are undersized in the ventilation configuration and operate continuously throughout most of the day.

The operating strategy proposed for the ventilation configuration was developed after reviewing the impact of residential electric demand on the total electric system load of the City of Austin's municipal electric utility. The system wide on-peak period is shown in the City of Austin's 1992 electric utility load research report as occurring between 2 p.m. and 8 p.m. (shown as shaded areas in Figures 10 and 11) in the months of May through October. This led to the concept of operating one undersized unit during the peak electric demand and the other during the off-peak period. The ventilation unit was found to be incapable maintaining acceptable indoor conditions during peak electric demand, but quite capable of this during the off-peak period. Additionally, the recirculation unit was able to maintain acceptable indoor conditions during the peak demand without simultaneously operating the ventilation unit.

Figure 10 shows indoor temperature and humidity are maintained within acceptable comfort limits for both the base case and ventilation configurations. Both configurations keep the indoor operative temperature below 79 ^{o}F (26.1 ^{o}C), the upper operative temperature limit for comfort as defined by ASHRAE (1992).

The cooling load reductions reported during the on-peak periods in Figure 11 are significant because they imply reduced system peak load. Austin's peak system load normally occurs on the hottest day of the year, i.e., day 5 in this simulation. Consequently, the reductions shown for the ventilation configuration should positively impact Austin's electric utility, since nearly 50% of Austin's system-wide peak load is attributed to residential electric load.

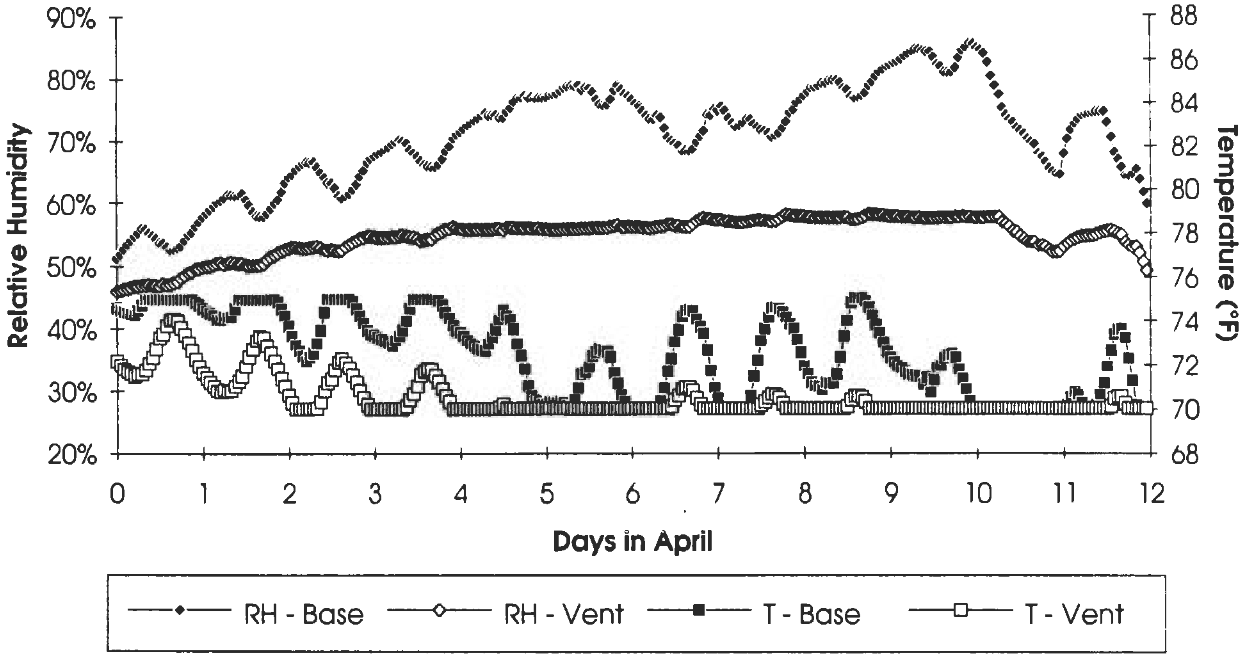

Figure 8 Ventilation Configuration Operating in April

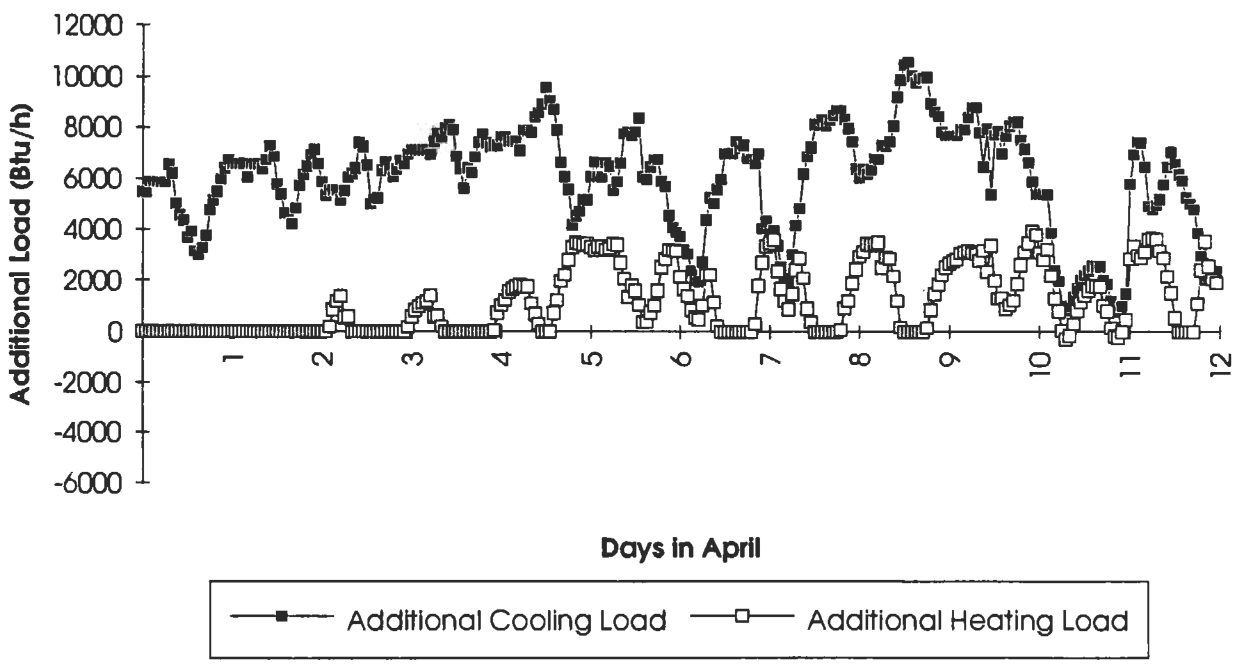

Figure 9 Additional Cooling and Heating Load for Operation of Ventilation Configuration in April

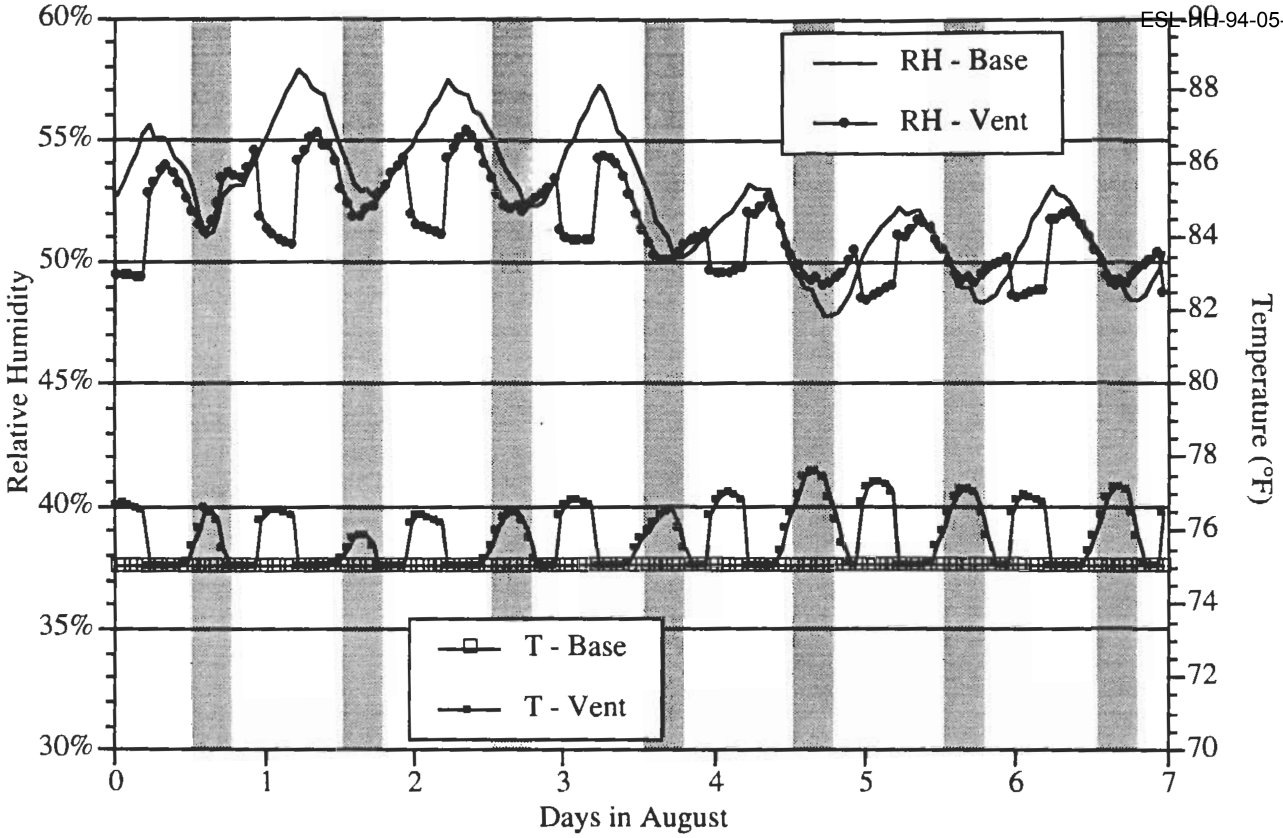

Figure 10 Operation of Base-Case and Ventilation Configuration in August

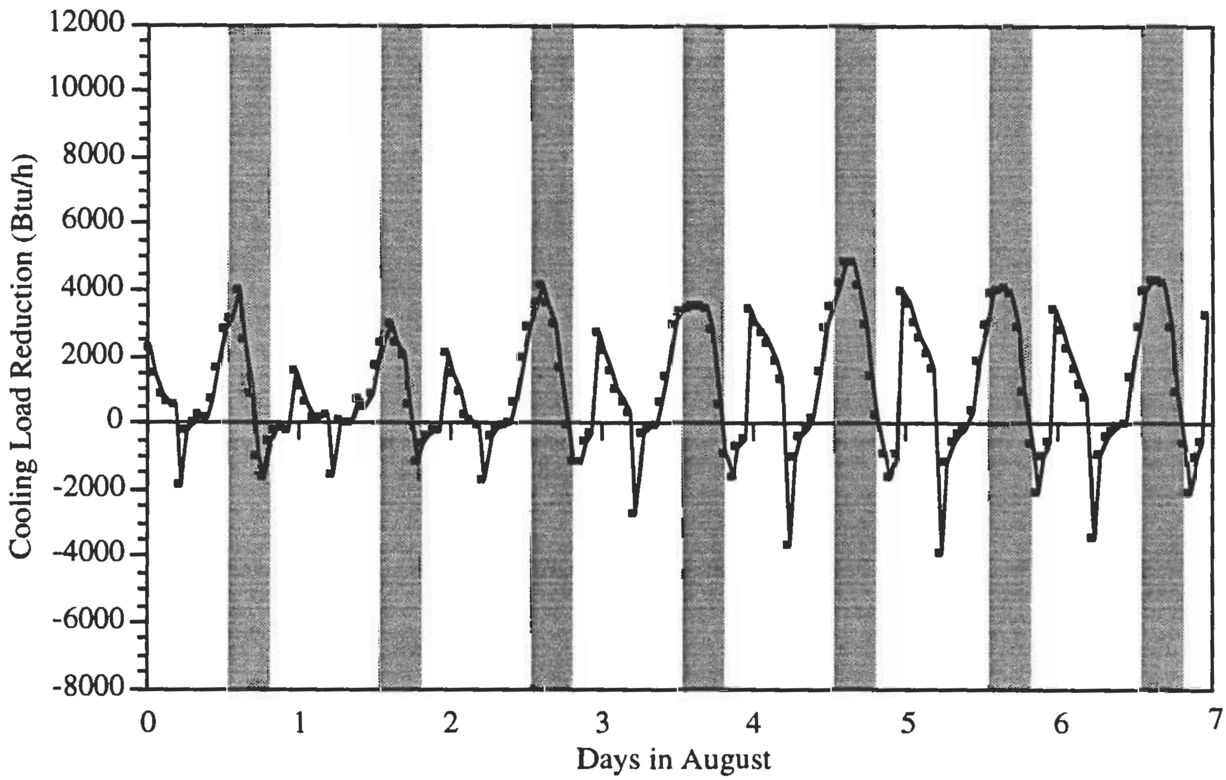

Figure 11 Reduction in Cooling Load for Operation of Ventilation Configuration in August

VENTILATION CONFIGURATION IMPROVEMENTS

At first glance, the ventilation configuration does not appear to be a cost-effective strategy to maintain indoor humidity during periods when ambient temperatures are moderate and humidity high such as those that occur in the Spring in Austin, Texas. As presented in this study, the concept employs two separate vapor compression units, which adds to both initial and maintenance costs. Furthermore, the ventilation configuration need not operate to maintain acceptable indoor humidity during the peak cooling season in Austin. Moreover, during its most effective operation, in terms of regulating interior humidity, the ventilation configuration overcools the residence, thereby requiring reheat which further adds to operational costs. Yet based on its ability to improve indoor humidity during the Spring as well as reduce peak electric demand during the summer, the ventilation configuration warrants further investigation.

Improvements could be accomplished by combining of the two units into one, with the flow rate of return and outside air regulated by a damper. This would be beneficial in that it would minimize initial and possibly operational costs. Coupled with an improved control that incorporates a thermostat and humidistat, the operation of the vapor compression equipment might be optimized. The crude control strategy applied in this study did not consider indoor conditions for ventilation unit operation, only ambient dry-bulb and manual scheduling, resulting in ventilation operation when it was not necessary.

Because the ventilation configuration employs vapor compression technology, it will most likely suffer from overcooling when operating during moist, mild periods. Concepts to overcome this drawback include the inclusion of a heat recovery coil similar to that used in grocery stores to reclaim waste heat from the condenser of the ventilation unit. A desiccant dehumidifier embodied within the ventilation configuration is another promising measure that could remove much of the latent load, or act as the complete dehumidifying system itself, when ambient temperatures are mild.

CONCLUSIONS

Based upon its ability to reduce peak electric demand and the fact that the development of this equipment is founded on a well-established vapor compression technology, the ventilation configuration has the potential for quick and widespread application in the residential air conditioning market. Although the ventilation configuration requires a number of improvements before it can be introduced to, or accepted by the general public, the concept does merit additional development.

Niche markets that might speed the adoption of this equipment, are located in the humid climates that exist along the Gulf Coast of the United States, Hawaii, and Mexico. Other opportunities for application exist in areas with high pollen or mold count. People who suffer from asthma and allergies might be the most motivated purchasers of such equipment.

REFERENCES

1. ASHRAE. 1989. *ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

2. ASHRAE. 1992. *ASHRAE Standard 55-1992: Thermal Environmental Conditions for Human Occupancy.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

3. Kerestecioglu, A.; M. Swami; D. Rajiv; N. Razzaq; and P. Fairey 1988. *Theoretical and Computational Investigation of Algorithms for Simultaneous Heat Moisture Transport in Buildings; Task 2 Final Report.* FSEC-CR-191-88 Cape Canaveral: Florida Solar Energy Center.

4. Kohloss, F. H. 1981. Opportunities to Save Energy in Tropical Climates, *ASHRAE Transactions*, Vol. 87, No. 1.

5. Trowbridge, J.; K. Ball; J. Peterson; B. Hunn; and M. Grasso 1994. Evaluation of Strategies for Controlling Humidity in Residences in Humid Climates. *ASHRAE Transactions,* Orlando, Florida.